ON THE NATURE OF ROENTGEN'S RAYS.

RARELY has a scientific discovery provoked such a stir in the world as that made in Würtzburg in December last by Professor Röntgen. Although Röntgen is a native Dutchman, he received his education and pursued his academic career entirely in German universities. A genuine German scholar, he was modest enough not to furnish the news of his surprising discovery immediately to the public at large, but contented himself with addressing his communication to the proper quarters—to his professional colleagues. It thus happened that scientists were the first to hear of the discovery, which was published in the Proceedings of the Würtzburg Physical and Medical Society in December, 1895, under the title "A New Kind of Rays." Röntgen, however, had scarce communicated his discovery to his colleagues before the papers took up the interesting questions which it offered, and in a few weeks the entire civilised world was familiar with its character.

Doubtless many a newspaper reader shook his head dubiously on hearing of the discovery, and may have gone so far as to denounce it as an imposture. But when reproductions of pictures taken by Röntgen's rays appeared in the periodicals and in the show windows, and when the German Emperor invited Röntgen to Potsdam to deliver an experimental lecture on the new "energy," the final doubts in the public mind were removed ; there was no thought of imposture, and it was recognised that we were confronted in Röntgen's rays with a discovery of stupendous scope.

Every educated man in the world now knows that physicists are able to produce invisible rays which have the power of penetrating more or less readily all substances, whether opaque or not,

and, having passed through them, of indicating on sensitive photographic plates, by the lightness or darkness of their impressions, whether they have passed through a great deal or only a little of the intervening substance, just as in photography heavy-black or light-black impressions of the plate show whether the rays have emanated from bright or from dark spots on the object to be photographed. But though this fact is familiar to every one, the previous history of the new physical agent and our surmises as to its character are unknown to the great majority of unprofessional readers, and to clear up this matter will be the object of the following pages, wherein we shall have to leave unnoticed the possible applications of the new discovery to anatomy and surgery, as these have already been sufficiently exploited in the press.

In the year 1789 the electric current was discovered by Galvani, of Bologna; but it was not until several years later that its most important properties, at least as distinguished from frictional electricity, were disclosed by Volta. Although galvanic batteries as a means of producing electric currents were studied and perfected in the next few decades, three great discoveries had yet to be made in the province of electricity before the new agent could attain the importance in civilised life which it to-day occupies, and before theoretical physics could investigate more closely its nature and character. These three discoveries were as follows:

1. In 1820 Oerstedt, of Copenhagen, discovered that an electric current flowing round a magnetic needle deflects the same, and that a magnetic needle rendered insusceptible to the influences of terrestrial magnetism and free to rotate in any direction, will place itself at right angles to the plane of an electric current surrounding it.

2. In 1825 Arago, of Paris, discovered that a piece of soft iron, about which a wire connected with a battery has been wound in spirals, is transformed into a magnet and continues in the magnetic condition as long as the circuit remains closed, but is again unmagnetised when the circuit is broken.

3. In 1831 Faraday, of London, discovered the so-called *induced currents* of electricity. If, he reasoned, the current was a source of magnetising action, as Arago had discovered, it was pos-

sible conversely that a magnet should be the source of a current-producing action. But Faraday found no confirmation of his conjecture. Twenty years later it could have been decided *a priori*, without experiment, that a magnet *at rest* could not give rise to a current. For that would have violated the law of the conservation of energy, agreeably to which work can be done only provided a like quantity of work has been previously expended in some way. Yet Faraday discovered the law, harmonising perfectly with the principle of the conservation of energy, that if a magnet be *approached* to a closed spiral circuit it will evoke in the circuit a sudden current lasting only for the moment of approach, but that when the magnet is *drawn away* from the spiral, a current in the opposite direction to the first will be momentarily set up therein. Instead of a magnet, a closed circuit carrying a current may be approached and removed, or instead of the latter the current in the circuit may be made alternately to appear and disappear, or its strength may be alternately increased and diminished.

Currents thus produced are called *currents of induction*, and apparatus designed to generate induced currents, rapidly alternating in direction, by means of common currents, are called *induction-coils*. An induction-coil consists (1) of a soft iron core, (2) of a primary wire spiral or helix enveloping the same and receiving an ordinary electric current, and (3) of a secondary wire spiral of thin wire and many turns, enveloping the first. The current sent through the primary spiral magnetises the iron core (compare the first discovery). The magnetised core then attracts a little iron hammer which is placed before it and regulated by a spring. This movement of the hammer breaks the metallic connexion with the primary spiral so that the current is interrupted and the iron core again unmagnetised. The hammer immediately jumps back from the iron core, the current is again set going, and the action described is repeated anew. By this apparatus, thus, we are enabled to make the current in the primary spiral repeatedly and alternately appear and disappear. According to Faraday's laws, now, every appearance of the main current in the primary coil must produce in the secondary coil an induced or *closing current*, as it is called, flowing in the opposite

direction and lasting but for a moment; whilst conversely every disappearance of the current must evoke an induced current flowing in the same direction with the main current, and called the *opening current*. Thus are produced in the secondary spiral in quick succession currents which flow in alternately opposite directions. These induced currents are of brief duration, but of enormous tension. Their powerful physiological action on the human body is familiar to every reader.

It is to these induction currents, discovered by Faraday in 1831, that we owe all the recent magnificent development of electro-technics. For not only is the art of telephoning based upon induction effects, but the performances of large dynamos, or machines designed to produce by mechanical work electrical currents of great intensity and high tension, are primarily rendered possible by induction effects. Without the discovery of induction it would have been impossible to illuminate a large city by thousands of arc-lights and to have replaced horse-power by electricity in our street railways. And also the more theoretical branches of physics—the physics of the laboratory—was started on a laborious but fruitful path of inquiry by this discovery of Faraday, the last station attained on which is Röntgen's rays.

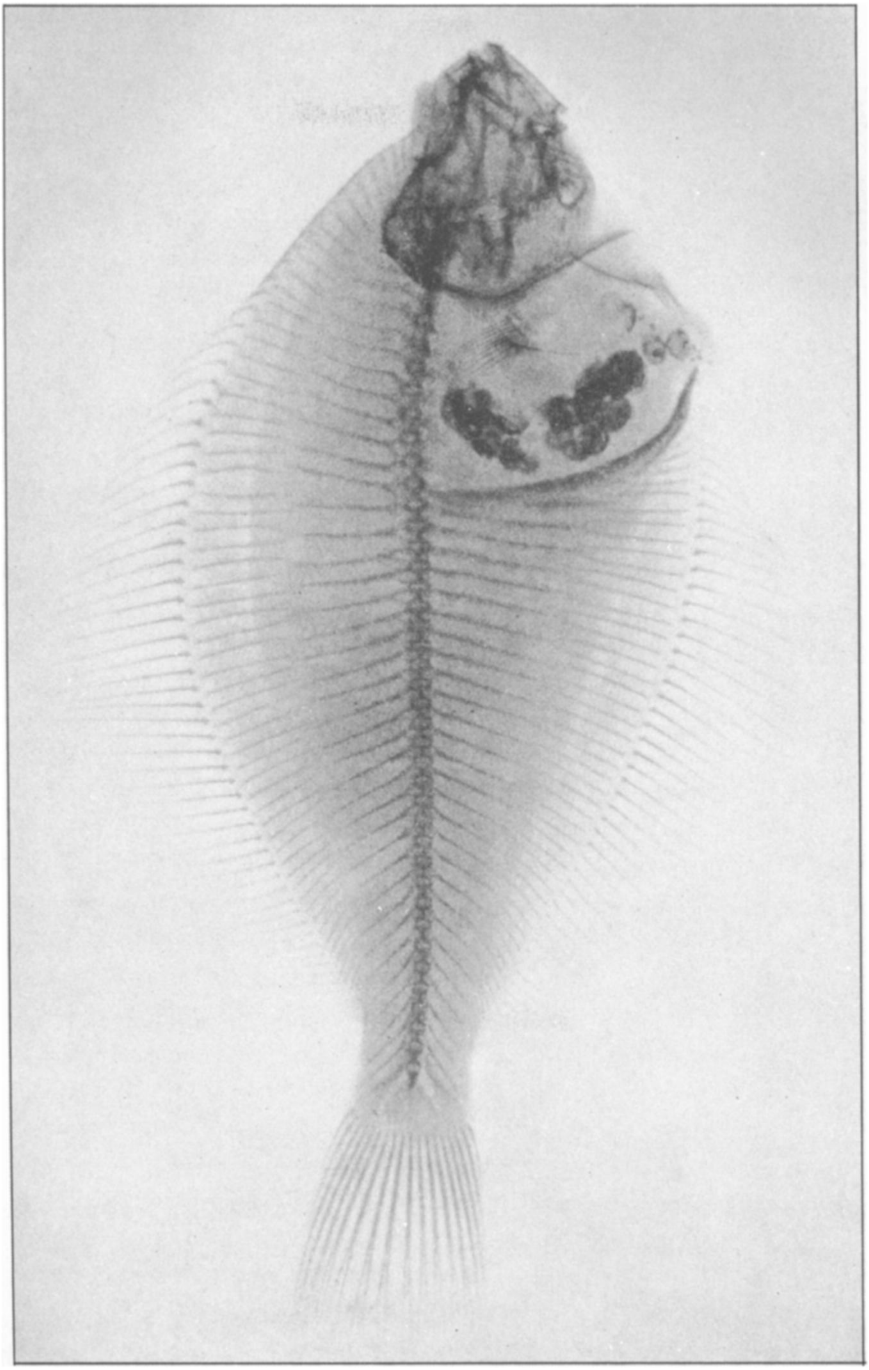
In the first place it was discovered that induced currents could bring to a state of incandescence rarefied gases enclosed in glass tubes. Along in the fifties, Geissler of Bonn succeeded with the help of a perfected mercury air-pump, in constructing tubes which exhibited this incandescence of enclosed gases in a marked and beautiful manner. Into the two ends of these tubes, which were named *Geissler's tubes* after their inventor, are soldered platinum wires, the terminals of which are called electrodes. If the tube be not too long and the induction current be powerful enough, the current will force a passage between the two electrodes and in so doing will set the enclosed gas through which it must pass, in a state of vivid incandescence. It is observed in the experiment that only the opening current and not the closing current has the power of producing this luminous effect. The closing current, in fact, is always considerably weaker than the opening current, for

the reason that it is set up in the direction opposite to that of the main current, whereby it detracts both from the strength of the latter and from itself. Consequently, inasmuch as the effect of the opening current is alone operative in Geissler's tubes, we can distinguish in this experiment between the two electrodes, seeing that one is the point of entrance and the other the point of exit of the positive current. The first is called the *anode* and the second the *cathode*. Now when induction-currents are passed through a Geissler's tube, a bright, narrow fringe is observed at the cathode and subsequently a relatively dark, bluish light, the *glow-light* or *cathode-light*, whilst at the anode as also in the largest part of the space intervening between the two electrodes striæ of bright and reddish-yellow light are distinctly visible.

In the year 1869, Hittorf, of Münster, dissatisfied with the degree of rarefaction attained by the Geissler tubes then in the market, arrived at new physical results by pushing the rarefactions of the tubes to a still minuter degree of density, amounting to more than the hundred-thousandth part of that of the ordinary atmosphere, and by substituting thin platinum plates for Geissler's platinum wire electrodes. It turned out that as the rarefaction increased, the bluish glow-light of the cathodes continued to spread, until it finally filled the whole interior of the tube. The phenomena which made their appearance on the passing of oscillatory induction-discharges through tubes containing such highly rarefied gases, were described by Hittorf in a paper which appeared in Poggendorf-Wiedemann's *Annalen* in 1869, and was entitled "On the Electric Conduction of Gases." Subsequently an English physicist, Crookes, made substantially the same observations, and founded upon them the hypothesis of the existence of a fourth aggregate state of matter. The bodies found in this state he called "radiant matter." This hypothesis was soon recognised to be untenable; but as Crookes knew better how to direct widespread attention to his work, the tubes exhibiting such phenomena have since been called Crookes's tubes, although it would have been more correct to have called them Hittorf's tubes. Latterly they have been called *vacuum-tubes*, as ex-

Actinogram of a lady's hand, showing the position of a needle broken off in the thumb and outwardly invisible. Taken by Roentgen's rays in the Physical State Laboratory at Hamburg, February 22, 1896.

(*a*) *Needle in the hand.* (*b*) *Common photograph of the needle after extraction.*



Actinogram of a young plaice (*Platessa*) with shells in its intestines. Taken by Roentgen's rays in the Physical State Laboratory at Hamburg, February 21, 1896.

pressing the enormous degree of gaseous rarefaction attained in them.

One of the most striking properties of the cathode-light in vacuum-tubes is that wherever it strikes the glass it produces a vivid glow, termed fluorescence. Particularly remarkable, also, is the phenomenon, likewise observed by Hittorf, that the cathode-light unlike the induction-spark does not follow the curvature of the tube but is always propagated straight ahead in a *rectilinear* path. In all these cases, the cathode-ray itself is invisible; its existence is made known only upon its striking some substance, on which it excites the fluorescent effect.

Of the remaining properties of the cathode-light the following are important. It can set in motion easily-rotating bodies on which it impinges. Heat is generated at spots where its rays strike, at times in sufficient quantities to set metals aglow. If the cathode be concave in shape the course of the light will be the same as that of the paths of common luminous rays emitted from a reflector. Lastly, we will mention the effect produced on the glow-light of the cathode by magnets, which was first carefully studied by Plücker, and subsequently by Hittorf and Crookes. Exposed to the action of a magnet this light behaves like a thin rectilinear conductor carrying a current and having one of its terminals attached to the cathode, but with its other, as also with its entire flexible length, following the magnet, in utter disregard of the position it assumes relatively to the anode or positive electrode.

Despite all this knowledge scientists as yet had reached no positive conclusion regarding the nature of the cathode rays, although Hertz had rendered it probable that we were dealing here, not with paths of electric currents, but with genuine rays of light.

Such was the state of our knowledge touching these cathode-rays when Hertz made his pioneer experiments proving the undulatory mode of propagation of electricity and showing that both light and electricity were based upon wave-motions of the ether and differed only in respect of the wave-lengths being short for the first and long for the last.

What is the relation, now, of the cathode-rays to the new view

of Hertz, that light and electricity both have their origin in undulatory motions of the ether? There are two kinds of wave-motion—transverse and longitudinal. We have an example of transverse undulatory motion in waves of water, where each water-particle ascends and descends vertically whilst the wave itself is propagated in a horizontal direction. We have an example of longitudinal undulatory motion in waves of sound, where every air-particle moves backwards and forwards in the same line in which the sound is propagated, and where at the same spot alternate rarefactions and condensations of the air are produced.

Now ordinary luminous and electrical phenomena can be satisfactorily explained by the assumption of transverse waves in the ether, which is not the case, however, with the cathode-rays. On this account, Hertz, as we now know, once incidentally expressed in a lecture the opinion that the cathode-rays owed their origin to longitudinal electric waves.

Filled with such thoughts, Röntgen was conducting his experiments with good vacuum-tubes, for the purpose of experimentally ascertaining the nature of the cathode-rays. In the course of his work he found that *the cathode-rays were the generators of a new kind of rays, which, since they differed from the cathode-rays, he called x-rays.* The chief characteristics which distinguish the x-rays from the cathode-rays are, first, that the cathode-rays, as explained above, can be deflected by a magnet, while the x-rays, when exposed to the influence of the same, continue their course in a *rectilinear* path without taking the least notice of the magnet; secondly, that the x-rays penetrate more or less readily *all substances*, whether visible or invisible, whilst the cathode-rays, as Lenard has shown, although capable of penetrating substances, yet have so little of that power that there can scarce be a thought of their practical application. Consequently, the x-rays cannot be simply continuations of the cathode-rays, but must be an entirely new kind of rays, which at present we can only produce by means of the cathode-rays, but which it is quite possible may at some time or other be evoked by other means.

Common attributes of the two rays are, first, that they can be

neither regularly reflected nor refracted; and secondly, that they give rise to fluorescence. The point whence the x-rays originate is the spot where the cathode-rays strike the glass wall of the tube. From this point they are propagated in right lines in all directions. It is impossible to concentrate them by means of glass lenses, as is done with common light in photography, because they cannot be refracted. Nor is it possible to deflect them by a mirror, because they cannot be reflected. Hence, in order to make use of them, it is necessary in all cases to obtain a straight line between their point of origin on the wall of the vacuum-tube, the object which they are to penetrate, and the plate on which the effect is to be recorded. Owing to the conditions imposed by this requirement of rectilinearity between tube, object, and field of action, *a limit is set to the application of the method which cannot be surmounted.* Suppose, for instance, that a pickpocket is desirous of knowing what money I have in my purse; my trousers' pocket and my purse will offer no obstacle to him, but he will be considerably hindered by the necessity of getting a straight line between the vacuum-tube, the money in my pocket, and his eye, or rather the photographic plate held before his eye.

But contrasted with their inability to be reflected and refracted, which forms a serious hindrance to the practical application of the x-rays, stands their other property, which renders possible their application in all provinces—we refer to the fact that *all substances are pervious to them in a greater or less degree.* It appears that substances of high specific gravity absorb more of the effects of the x-rays than substances of low specific gravity, that is, are less pervious to them than the latter. For example, an aluminium plate must be three and one-half millimetres thick in order to absorb as much of the x-rays as a zinc plate one-tenth of a millimetre thick. Yet it is not to be supposed that the absorption of x-rays is proportional to the product of the thickness of the plate and the specific gravity of the substance of which it consists. All that is certain is that given the same thickness heavier substances absorb more than lighter substances. The different degrees of permeability to the x-rays shown by different substances may be clearly seen from the

hand reproduced in *The Open Court* of February 6, where the soft parts, cartilage, bones, and the gold of the engagement-ring are distinctly recognisable by the varying darkness of the parts.

The most important of the known properties of the x-rays are, first, that they produce fluorescence, and, secondly, that they are capable of producing chemical effects, even after they have passed through opaque and dense solids on their way from the vacuum-tube. This fluorescence may be evoked in a large variety of substances, like glass, quartz, etc., but its effect is most marked and vivid in barium platinocyanide. Röntgen had wrapped black paper round his vacuum-tube, and made the room totally dark. A paper screen painted with barium platinocyanide then glowed brilliantly whenever a discharge was passed through the darkened vacuum-tube.

We have made use of this property here in the Hamburg State-Laboratory in order to ascertain quickly whether a tube was sufficiently exhausted to emit the x-rays. For this purpose a blackened cylinder was used, to the end of which a crystal of barium platinocyanide had been attached. This cylinder was held before the eye, and the vacuum-tube observed through the blackened cylinder. On the making of the discharge, every time the crystal glowed the x-rays could be successfully employed for photographic purposes, but whenever the glow was imperceptible, the vacuum-tube was unfit for this use.

"*X*-spectacles" is the name the author has given to a little apparatus made of two such tubes, furnished with suitable fastenings behind the ears, and designed for both eyes. Paper coated with barium platinocyanide may also be used in place of the crystal. Equipped with a pair of x-spectacles, a man can tell by the relative intensities of the fluorescent spots whether the x-rays impinging on these spots have passed through much or little substance, and, under favorable circumstances, by this means we may detect the shape of dense objects enclosed in small, light boxes. For example, if we hold a little paper box made to contain a ring between the vacuum-tube and the x-spectacles, we can tell whether the box is empty or whether the ring is in it. Important improvements will be made

in the x-spectacles when scientists shall succeed in constructing chemically prepared plates which are as perfect as those at present in use in photography, but which shall differ from them in being totally insensitive to common light, while at the same time capable of receiving the impressions of the x-rays. A plate of this kind will be better than paper coated with barium platinocyanide, for the reason that the chemical changes evoked on the plate by the varying intensities of the incident x-rays would cause the object to stand out in far sharper relief than would the transient action of fluorescence. But there would be this drawback attending the operations of a man whose eyes were equipped with such an improved pair of x-spectacles, that he would have to insert new spectacle-glasses for every new object seen.

In the possibility last set forth we have mentioned the second of the two properties which have drawn the attention of the civilised world to the x-rays. The first of these two properties was that the rays penetrated all substances, though in varying degrees. The second is their power of producing chemical effects on photographic plates. By the intensity of their chemical effects on such plates the x-rays indicate the relative amount of substance they have passed through, and for this reason the description "photography of the invisible" has been justly applied to the new discovery. Even though a body be totally opaque, yet the molecular composition of its interior can be disclosed by the chemical action of the x-rays, especially if the vacuum-tube be brought to bear upon it from all sides. So far, only the common photographic plates have been generally employed for receiving the impressions of the x-rays. But it is quite unlikely that these plates are the best fitted for this purpose. It is a duty devolving on chemists and photographers, therefore, to discover experimentally the substances which are most sensitive to the x-rays, so that plates can be constructed which are better adapted than the common photographic plates for revealing the interior solid constitutions of bodies.

As the x-rays differ from the common light-rays by being incapable of regular reflexion and refraction and by suffering greater or less relative absorption, their effects on chemically prepared

plates and the employment of these effects for the manufacture of pictures cannot be called photography, or *light*-drawing. We might, perhaps, since their discoverer Röntgen has preferred the expression x-rays, say *x-ography* instead of photography, and this word has been actually used. Other physicists have formed the words *actinography* and *actinogram* from ἀκτίς (gen. ἀκτῖνος), the Greek word for ray,—compounds which are not objectionable and which we shall use in the following.

We have referred to the construction of plates highly sensitive to the impressions of the x-rays as a technical problem of supreme importance provided actinography is ever to realise the expectations which physicians are already cherishing with regard to it. But we have to look upon the construction of suitable vacuum-tubes as a task of no less practical importance. The majority of tubes, even when purchased for Crookes's tubes, turn out to be useless. The members of the Hamburg State-Laboratory originally had the glass of their tubes made to order but undertook themselves the rarefaction of the air, which latter they accomplished by means of good mercury air-pumps. In this way a rarefaction of approximately one-millionth of the density of our atmosphere has been obtained.

But even the tubes thus constructed were not always fit for use. A few weeks ago tubes were received from the present proprietors of the firm of Geissler in Bonn, which were guaranteed to be adequately exhausted. On their arrival they at first proved to be unfit for use, but after they had remained lying several weeks, strange to say, they were found serviceable. A large number of the actinograms made in the Hamburg State-Laboratory have been produced by a tube which was permanently connected with a mercury air-pump. Whenever the tube ceased to work,—a condition readily discovered by means of the x-spectacles,—the pumping was continued till it reacquired its original power, usually after the lapse of a brief space of time.

In the last few days (Feb. 25) another important advance in this direction has been made in the Hamburg State-Laboratory. By the use of a newly patented mercury air-pump just obtained from Berlin, and automatically working by the suction of water, and sec-

ondly by the application of a method for removing the particles of matter that adhere to the inner walls of the tube and which at low pressures are readily transformed into gas, tubes have been constructed and are there in use since Friday, the 21st of February, which yield actinographic results far superior to anything obtained by the old tubes. Also the last tubes which have just recently been received from the firm of Geissler in Bonn are incomparably better than their first ones.

Three actinograms taken by the new improved tubes are particularly worthy of notice: (1) the actinogram of a plaice which has swallowed shells (its reproduction will be found accompanying this article); (2) an actinogram of an aborted human fœtus twelve to thirteen weeks old (unpublished); (3) the actinogram of a lady's hand into which a needle had been run a short time previously, and of which there was no outward trace (also accompanying this article). In the last case the surgeon who had brought the lady to the Laboratory removed the needle after a mere glance at the negative. The photograph of the needle was then placed side by side with the actinogram.

Further, the actinograms taken by the new tubes differ from the old ones not only in distinctness but also in the time of exposure required. With the new tubes the interior of the hand was taken as distinctly in five minutes as it had been with the old tubes in twenty minutes. The attempt will be made in a few days to actinograph the whole human body. It is to be sincerely hoped that these experiments will be successful, although of course the time of exposure will be considerably longer.

The merit of having successfully repeated Röntgen's experiments as early as the middle of January, and of having obtained unusually good negative actinograms at about that time, belongs to Professor Voller, the Director of the Hamburg Physical Laboratory. Dr. Voller also drew attention to the fact that vacuum-tubes in which induction-discharges are taking place *grow hot when they emit no x-rays*, that is, are unfit for actinographic purposes, *but remain cold when they do emit x-rays*, that is, are fit for actinographic service. This fact is important as showing that the *x*-rays constitute a new

form of energy into which the electric energy appearing in the vacuum-tubes can be transformed. When this electric energy is transformed into heat, it can then not be re-transformed into the new x-energy, and *vice versa*.

It will be seen, thus, that the Röntgen rays fall within the scope of the law of the conservation of energy, agreeably to which work can never be produced unless an equivalent quantity of work, be it in another form or not, has been expended, and conversely, work can never disappear without an equivalent quantity of work appearing in some other form. This great law is the monistic principle which embraces all physical forces, and also the newly discovered force.

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